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Ecological studies of soil organisms with references to the decomposition of pine needles

I. — Soil macrofaunal and mycofloral surveys in coastal pine plantations*

BY

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INTRODUCTION

Research in soil biology has shown that both the soil animals and micro-organisms are important in the decomposition of plant litter. It is therefore essential that we understand the interrelationships between them (e.g. MACFADYEN, 1968; SZABÓ, 1974; SATCHELL, 1975; WITKAMP and AUSMUS, 1976; REYES and TIEDJE, 1976; LATTER, 1977).

The primary aim of this study was to obtain some fundamental information on the predominant groups of macrofauna and of mycoflora on the floor of a Japanese black pine forest (*Pinus thunbergii* Parl.). This is a common forest type along the coast of the mainland of Japan. An attempt was also to study the relationship between populations of the isopod (*Porcellio scaber* Lat.) and the mycelial development of basidiomycetes. The advantages of studying soil biology in the coastal pine plantation lay not only the simplicity of the vegetation and topography, but also in the easily recognisable progressive stages of decay of the needles.

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I. — DESCRIPTION OF STUDY AREA

A. Location and vegetation.

The study area is in a plantation of *P. thunbergii* at Fukanuma beach on the Pacific coast, located about 10 km to the southeast of the city of Sendai, Miyagi Prefecture. This forest, with various stages of development, covers a 300 to 500 m wide band on both sides of the Teizan canal, running along the coastline as shown in Fig. 1. On the Pacific side of this plantation, there is a stretch of sand beach and an expansion of the cultivated fields to the inland side. Seven sites were chosen for the faunal surveys, the details were as follows:

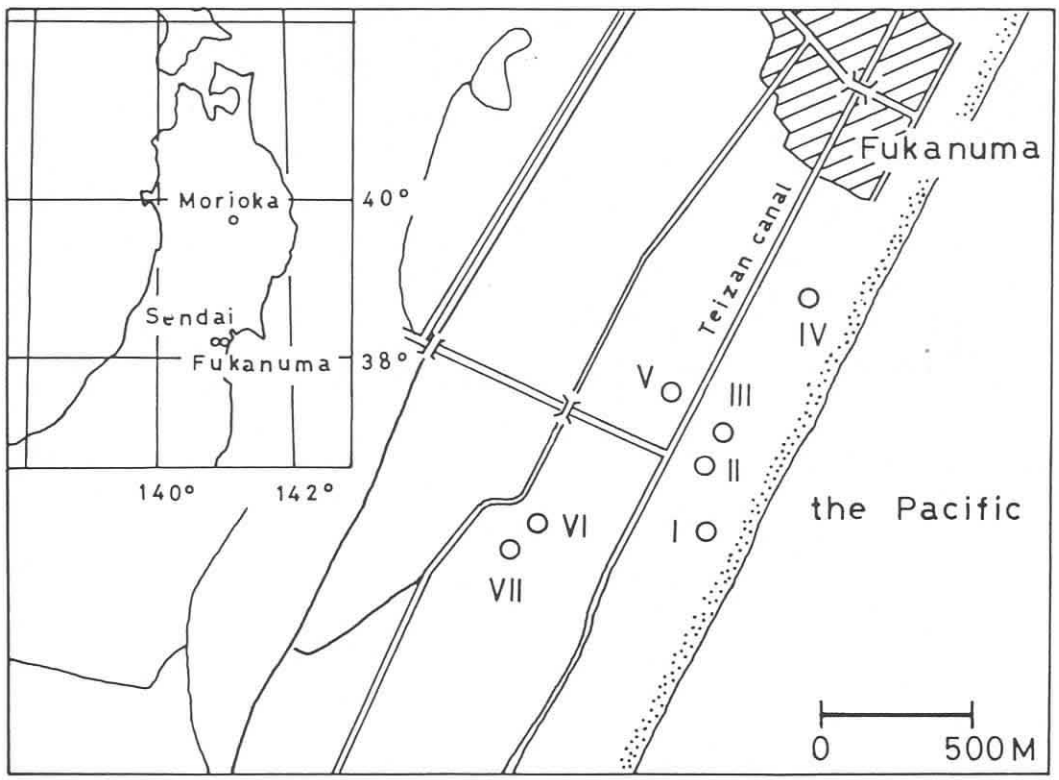

FIG. 1. — Map showing the area studied.

Site I: This site is about 160 m inland from the tidal line. The clumps of stunted pine ca. 2 m high and 6 cm in diameter at the base are found scattered on the open sand. A thin cover of needles overlays the sandy surface only around the base of the trees where the samples were taken.

Site II: This plantation consists of pine 4 m high with D.B.H. (diameter at breast height) of ca. 4 cm. The forest floor is open and the A_0 layer is less than 1 cm thick.

Site III: This plantation has a close canopy formed by a pure stand of pine 10 m in height and 15 cm D.B.H. A thick carpet of needles can be divisible into L, F_1 and F_2 layers. The samples were taken from low lying places where the A_0 layer exceeded a depth of 10 cm.

Site IV: This stand is similar to site III but has a sparse shrub layer consisting of *Robinia pseudo-acacia* L. The same is true of the A_0 layer 3.5 cm in depth.

Site V: This plantation is composed of pine trees with crooked trunks some 15 m high and 12 cm D.B.H. forming an open canopy. The ground layer consists for the most part of tall grass, *Miscanthus sinensis* Anders. and has an A_0 layer 4 cm deep.

Site VI and VII: These are mature black pine woods mixed with red pine (*Pinus densiflora* Sieb. et Zucc.) spread over the hinterland and forming a close canopy. The understory at both sites comprises various deciduous broad-leaved trees as well as the pines. At site VI the lower tree layer is almost destitute of deciduous trees, but the shrub layer is covered with *Tripetaleia paniculata* Sieb. et Zucc. At site VII *Prunus gratana* Maxim., *Quercus serrata* Thunb. and *Rhus trichocarpa* Miq. are common members of lower tree layer, while *T. paniculata* and *Rhododendron japonicum* (A. Gray) Suringer are common in the shrub layer. Besides, *Ardisia japonica* (Thunb.) Blume and *Vaccinum hirtum* Thunb. var. *Motosukeanum* (Koidz.) Sugaya are abundant in the ground cover of both sites. The A_0 layer ca. 5 cm deep has a well-defined H layer as compared with those of the foregoing sites.

The climatic records for this area during the four years of study (1974-1977) were taken from the Sendai district meteorological observatory located in the centre of the city; the mean annual air temperature was 11.7° C, the mean monthly temperature ranged from 0.3° C in January to 23.3° C in August, the minimum and maximum temperatures were — 9.3° C in January 1977 and 34.9° C in August 1975 respectively. The average annual precipitation is 1265 mm, distributed mainly during the summer and autumn seasons.

B. **Characteristic features of the decay of pine needles.**

The pines shed more than half of their needles in late October to early November in this district. Observations on the decaying of the needles were carried out in sites III, where the needle litter layer is well developed. The criteria for the leaf descriptions are based mainly upon colour, texture and tensity of the needles.

In the present study there seem to be two patterns in terms of the darkening and decolouring processes, similar to that seen in beech leaves by SAITÔ (1966). The darkening proceeded progressively through brown needles in the L layer, dark brown needles to blackish brown needles in the F_1 layer. On the other hand, the decolouring process was characterized by the overwhelming growth of litter-inhabiting basidiomycetes forming yellowish needles in the F_1 layer and yellowish, decayed compactly compressed needles in the F_2 layer. Practically speaking, however, these two processess were so closely linked and intermingled together that they could not be separated in nature.

Most needles fragments in the lower layer bear various kinds of pellets. Among these the characteristic oblong pellets of an isopod and those of earthworms were noticeable. Frequently, these faecal pellets spread sporadically in sheets underneath the F layer.

II. — MACROFAUNA IN A VARIETY OF SITES

A. **Methods.**

Using 50 × 50 cm quadrats, samples were taken from the following soil horizons; A_0 layer, 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm. All animals over 2 mm in body length were collected by hand sorting exclusive of Enchytraeids, springtails, ants and mites.

These were immediately stored in 75 % ethanol, then the identification and counting were done in the laboratory. The first survey was carried out at sites I, II, III, IV and V in June, 1974 and the second, at sites III, V, VI and VII in May, 1975. Estimations of biomass were performed only in the latter samples and the values for 1974 were evaluated on the basis of the actual ones in 1975. The percentage organic matter, as measured by loss on ignition at 700° C in a muffle furnace, was determined on the surface soil of each site. The determination of pH of the same samples was performed on the soil suspensions using a glass electrode.

B. **Results and discussion.**

1. *Salient features of faunal composition.*

The faunal composition of the soils is given in terms of number and biomass in Table II. In all 3608 individuals belonging to 13 orders were collected, of which 4 orders, the Isopoda, Araneida, Diptera and Coleoptera

TAB. I

Loss on ingnition (%) and pH (H_2O) measurements refer to surface soils

Site	I		II		IV		V		VI		VII	
Depth (cm)	Loss on ignition	pH	Loss on ignition	pH	Loss on ignition	pH	Loss on ignition	pH	Loss on ignition	pH	Loss on ignition	pH
0-5	0.89	5.9	1.21	5.5	1.37	5.5	2.03	5.0	7.07	4.7	6.04	4.8
5-10	0.76	5.9	0.81	5.8	0.94	5.8	1.54	5.4	3.39	5.2	2.40	5.3
10-15	0.68	6.3	0.69	6.1	0.93	5.9	1.18	5.6	1.38	5.6	1.48	5.5
15-20	0.62	6.7	0.85	6.5	0.42	6.2	1.07	5.6	1.48	5.7	1.33	5.6

including the Scarabaeidae, were widely distributed in all of the sampling sites. Of these the Isopoda represented exclusively by *P. scaber*, were remarkable for population density or biomass. Next in abundance were the Araneidae, though they were not important in terms of biomass. The Diptera and Scarabaeidae (mainly larval forms) were not abundant. Opisthopora, Lithobiomorpha, Hemiptera, Lepidoptera and Staphylinid and Harpalid Coleopterans were found in almost all sites in varying proportions over a wide range of habitats. They were absent, however, from sites I and/or II where the vegetation and organic layer was scant. Of these, the Opisthopora consisting of a few species of earthworms were the outstanding component of fauna in terms of both abundance and biomass at sites VI and VII, where the humus layer was rich in organic matter (Tab. I). The Harpalidae were relatively abundant in the mature plantations, particularly at site III in 1974. Of the remaining minor groups of fauna, the distribution of the Geophilomorpha, and the Elaterid and Curculionid Coleopterans were confined to three of four sites. Stylommatophora, Scolopendromorpha and some Coleoptera occurred in only one or two sites.

TAB. II

Soil macrofaunal composition indicated by numbers (No. of individuals/square meter) and biomass (wet weight / square meter) in a variety of pine plantation during 1974 to 1975

		Site I '74		Site II '74		Site III '74		Site IV '74		Site IV '75	
		No.	W.W.	No.	W.W.	No.	W.W.	No.	W.W.	No.	W.W.
Mollusca	*Stylommatophora*	0	0	0	0	0	0	3	16	3	16
Oligochaeta	*Opisthopora*	0	0	0	0	28	1,484	5	265	7	279
Chilopoda	*Geophilomorpha*	0	0	0	0	9	0	0	0	0	0
	Lithobiomorpha	0	0	1	14	0	0	0	0	8	90
	Schlopendromorpha	0	0	0	0	0	0	0	0	2	29
Diplopoda	*Polydesmoidea*	0	0	0	0	0	0	0	0	0	0
Crustacea	*Isopoda*	23	380	83	1,370	810	13,365	197	3,251	237	3,821
Arachnida	*Araneida*	4	14	13	46	74	259	31	109	70	109
Insecta	*Diptera*	1	14	(2)	26	6(6)	155	2(15)	219	(1)	1
	Hemiptera	0	0	0	0	1	50	0	0	(1)	+
	Orthoptera	0	0	(1)	3	0	0	0	0	0	0
	Lepidoptera	0	0	0	0	(2)	27	(2)	27	0	0
Coleoptera:	*Scarabaeidae*	1	137	1(10)	1,502	(1)	137	(8)	1,092	0	0
	Staphylinidae	0	0	1	5	2(1)	16	6	31	0	0
	Harpalidae	0	0	6	146	94	2,341	406	10,109	65	1,737
	Elateridae	0	0	(10)	150	(1)	15	(1)	15	0	0
	Pselaphidae	0	0	0	0	0	0	0	0	0	0
	Curculionidae	0	0	0	0	0	0	0	0	0	0
TOTAL		29	545	128	3,262	1,026	17,849	676	15,134	394	6,082

		Site V '74		Site V '75		Site VI '75		Site VII '75	
		No.	W.W.	No.	W.W.	No.	W.W.	No.	W.W.
Mollusca	*Stylommatophora*	0	0	0	0	0	0	0	0
Oligochaeta	*Opisthopora*	6	318	9	325	66	2,554	53	3,996
Chilopoda	*Geophilomorpha*	0	0	3	32	9	73	9	47
	Lithobiomorpha	8	108	17	265	1	9	6	68
	Schlopendromorpha	0	0	0	0	1	29	0	0
Diplopoda	*Polydesmoidea*	1	+	0	0	0	0	0	0
Crustacea	*Isopoda*	120	1,980	131	2,337	236	3,518	192	3,470
Arachnida	*Araneida*	83	291	41	90	74	280	38	297
Insecta	*Diptera*	(1)	13	(5)	239	(41)	374	(6)	68
	Hemiptera	1(7)	59	1	55	1	44	(7)	9
	Orthoptera	(2)	6	0	0	0	0	0	0
	Lepidoptera	(1)	14	(1)	19	(3)	16	(3)	61
Coleoptera:	*Scarabaeidae*	(1)	137	(2)	605	(8)	887	(1)	10
	Staphylinidae	2	10	11(1)	38	7(3)	46	12(4)	81
	Harpalidae	24	598	33	734	22	521	33	814
	Elateridae	0	0	(1)	15	0	0	0	0
	Pselaphidae	0	0	0	0	1	2	1	2
	Curculionidae	0	0	2	1)	1	12	1	9
TOTAL		257	3,534	258	4,755	474	8,365	366	8,932

Numbers in parentheses indicate number of larvae. + indicates less than 1 mg in biomass.

Considering the relationship between fauna and habitats, the sparsest fauna in terms of diversity, abundance and biomass was seen at site I, the richest at VI and VII and sites II to V were intermediate. The number of individuals ranged from 128 to 1,026/m² and the biomass from 3.5 to 15.1 g/m² in the sampling area except for site I. These figures are roughly comparable to those of other workers in black pine forests of Japan, although there is a considerable difference in faunal composition. KITAZAWA and KOBAYASHI (1958) reported 2.3 to 4.2 g/m² in biomass in the Shimokita peninsula. The values of KITAZAWA et al. (1960) can be roughly calculated to be 245/m² in number and 5.6 g/m² in biomass, if ants, springtails and mites are excluded from their data from the Osumi peninsula. Recalculation of Watanabe's data (1971) on the alien pine plantation near Kyoto, yields mean values of 144 to 274/m² in number and 4.3 to 6.0 g/m² in biomass and 95 to 240/m², and 4.3 to 66.2 g/m² in the *P. strobus* and *P. ellioti* forests respectively although the last biomass figure was exceptionally high due to the occurrence of a large earthworm, *Pheretima sieboldi*.

The prominent species in our studies, *P. scaber*, accounted for more than 50 % of the total number of animals in almost all sites, although the density ranged from 83 to 810/m². Clearly, they increase with the accumulation of needles, showing the highest density in site III where the A_0 layer was deepest. A similarly high density (333/m²) has been recorded by Soma (1975) in the black pine plantation of Enjuga beach in the Pacific coast, Wakayama Prefecture. According to Watanabe and Shidei (1963), the density of isopoda in the inland coniferous forest near Kyoto was 0-5/m² in *P. densiflora*, 0-15/m² in *Cryptomeria japonica* and 5-35/m² in *Abies firma*. Kato's data (1976) showed the density up to about 200/m² on *Ligidium* population in the *Cryptomeria* plantation of the Boso peninsula. Compared with these data the population of woodlice in the pine woods near the beach seem to be expected to show a higher density. It is also noteworthy that the proportion of *P. scaber* to the total biomass ranged from approximately 30 to 80 % throughout all the sites. As far as coniferous forests are concerned, the woodlice are known as a minor group. It is noticeable, however, that the populations in this pine plantation are the most important component of the soil fauna. In view of the fact that *P. scaber* is a detritivore, their participation in the degradation of pine nedles may be highly significant in the present habitats.

2. *Vertical distribution of macrofauna.*

The vertical distribution of macrofauna expressed as the percentage of total numbers at each site, shown in Fig. 2 gives two types of curve. One type seen in sites I to V shows a rapid fall in numbers with depth, with more than 80 % of the total numbers concentrated in A_0 layer. The other type which shows only a slight decrease between 0 and 5 cm was observed in sites VII and VIII and at site IV in 1974. The discrepancy between the years at site IV sems to be caused by the great abundance of Harpalidae.

The distribution of the six major groups in the study sites is shown in Fig. 3 combining sites I to V and sites VI and VII as these site groups had similar distribution curves. In sites I to V the distribution of all except the Harpalidae tend to be concordant with the first distribution shown in Fig. 2, although the proportions vary from group to group. At sites VI and VII

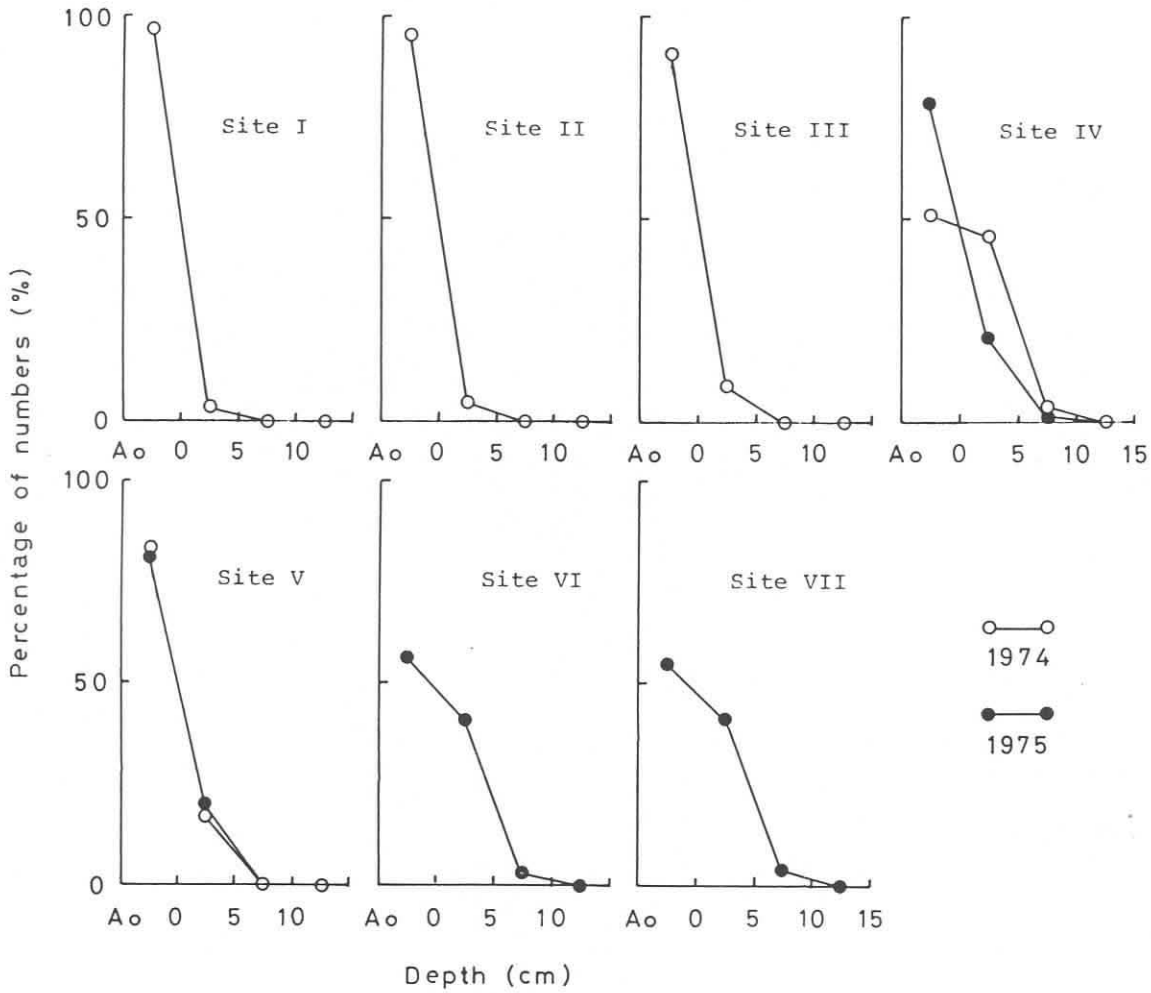

FIG. 2. — Vertical distributions of total population in each of sites, expressed as percentages of numbers in each horizon.

Opisthopora, Staphylinidae, Diptera larva and Harpalidae were highest at 0-5 cm depth, but Isopoda and Araneida showed a peak in the A_0 layer. Therefore, the distribution curve has a gentle slope betwen the A_0 layer and 0-5 cm corresponding to the second curve type of Fig. 2. In another words the humus soil layer supports groups of fauna in great profusion.

In all the habitats, *P. scaber* had a maximum population in the surface layer. According to DAVIS, HASSALL and SUTTON (1977) working on the vertical distribution of isopods and diplopods in a dune grassland, *P. scaber* was always nearest the surface and it came between *Philoscia muscorum* and *Armadillidium vulgare* with respect to vertical movements.

Another indication of the importance of vertical distribution is the fact that there was no macrofauna in soils deeper than 10 cm or 15 cm. However, it is generally accepted from the results of many workers that some members are able to dwell up to 50 to 100 cm or more deep in the forest soils. This inconsistency seems to be based on the nature of surface soils. In fact, the compact top soil, bound tightly by fungal mycelia appears to prevent most macro-animals from moving downwards, with the exception of typical burrowers such as the Harpalidae.

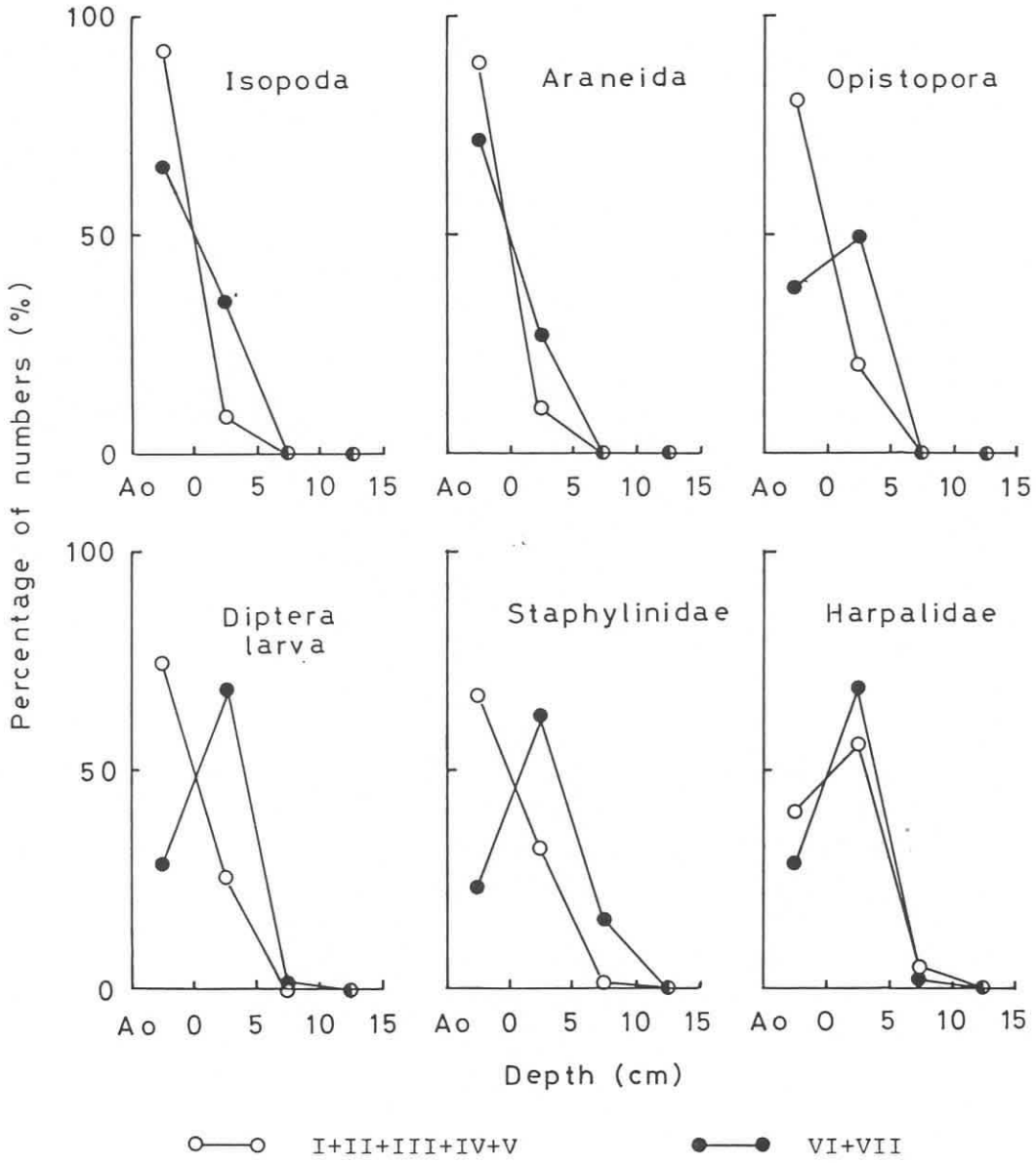

FIG. 3. — Vertical distribution of six major groups of fauna in two sections of sites, expressed as percentages of numbers in each horizon.

III. MYCOFLORA IN RELATION TO DECAY OF PINE NEEDLES

A. Methods.

Although this fungal study was mainly a qualitative survey, it is comprehensive in that it deals with both macro- and microfungi. The study area were chiefly restricted to sites II, III, IV where pine needles accumulated on the floor. For the surveys of macrofungi such as visible cup fungi, agarics and boleti, frequent visits were made from 1975 to 1977, and about once a week between April and November in 1977. These investigations focused on the determination of the principal members of the Basidiomycotina found on the needles and on their relations with the substrate, including mycorrhizal associations. Particular attention was paid to the mycelial growth patterns around basidiocarps occurring on the litter and in the underlying soil layers. These were carefully examined by digging and tracing. In addition to the field observations, microscopic examination was used for the examination of fine mycelial structures.

The main member of the microfungi, including the conidial states of macrofungi and microscopic ascocarps, were studied using the complementary methods of direct microscopic observation, damp chambers and cultural methods, combined with washing/surface sterilization techniques. The medium for isolation most commonly employed was malt extract agar or glucose peptone agar with chloramphenicol (50 μg/ml).

For evaluation of the main species, relative abundance was used as an approximate, composite measure of frequency and abundance for both macro- and microfungi.

B. **Results and discussion.**

1. *Non-basidiomycetes.*

Over 50 species belonging to the Zygomycotina, Ascomycotina and Deuteromycotina were recognized from a variety of pine needles. Of these, the major species will be described in this section with reference to the substrate groups of GARRETT (1956, 1963), including the improvements by KENDRICK and BURGES (1956) and HUDSON (1968). These are listed with the appended litter-inhabiting Basidiomycotina in Table III in connection with the stages of decay.

TAB. III

Major species of fungal group (excluding mycorrhizal fungi) associated with decaying of pine needles

	Living needles	Brown needles	Dark brown needles	Blackish brown needles	Yellowish needles	Yellowish decayed needles	H layer
Aureobasidium pullulans (de Bary) Arn.	c	f					
Cladosporium spp.	c	f					
Pestalotia sp.	c	f					
Phoma sp.	f						
Lophodermium pinastri (Schrad.) Chev.	a	a					
Cenangium sp.	a	a	a	f			
Desmazierella acicola Lib.		f	a	a			
Endophragmia allernata Tubaki & Saitô			a	a			
Unidentified-F1051			a	a			
Kriegeriella mirabilis Höhn.			c	a			
Marasmius androsaceus (L. ex Fr.) Fr.			a	a		a	
Collybia confluens (Fr.) Quél.					a	f	
Collybia dryophila (Fr.) Quél.					f		
Mortierella ramannianus (Möller) Linnem.				f			c
Penicillium spp.				c			a
Trichoderma spp.				c			a

Symbols: a, abundant; c, common; f, frequent.

The phylloplane fungi on the living green needles were *Aureobasidium pullulans* (De Bary) Arn., *Cladosporium* spp. (mainly of *C. cladosporoides*) and black yeasts which usually appeared with a restricted form around the stomata. As the needles became moribund, these fungi extended their mycelia and remained active on the brown needles for some time after leaf-fall.

One of the most prevalent species of facultative parasite or weak parasites *Lophodermium pinastri* (Schrad.) Chev. invaded the living needles in advance with the latent period. On the ground it continued to colonize the brown needles and remained for 6 to 9 months until the maturation of the hysterothecia. The present study did not undertake the detailed observation with another *Lophodermium* species that were disclosed by MILLAR and his colleagues (1978 abc). The mycelium from a *Cenangium* sp. was usually isolated from the interior of the living needles, especially the basal part, though there were no disease symptoms. This fungus also continued to grow intensively in the fallen needles for more than one and a half years and fruited profusely on the dark brown and blackish brown needles in the moist period of May to July. In this connection GREMMEN (1957, 1960) has noticed *Cenangium acuum* on the Scots pine needles of felled trees in dry conditions. According to Dr. R. W. G. DENNIS (personal communication), the present species of *Cenangium* appears to be distinct from *C. acuum*. At any rate, this species of *Cenangium* may be one of the internal colonizers as well as a non-pathogenic facultative parasite. Both *Pestalotia* sp. and *Phoma* sp., particularly the former, were found on the living needles using both cultural and damp chamber methods. They differ from *Cenangium* and *Lophodermium* in disappearing during the early stage of the brown needles. The fact that *Pestalotia* is abundant here contrasts with the results of British workers and should be noted. Somewhat similar results to ours concerning *Pestalotia*, were found in *Pinus taeda* by WATSON, MCCLURKIN and HUNEYCUTT (1974).

As the brown needles become moist in the L layer, the secondary saprophyte groups which possess a wide variety of characteristics appeared gradually in the interior and the exterior of the needles. *Desmazierella acicola* Lib. (*Verticicladium trifidum* Preuss, imperfect state) known as specific to pine needles was found, attacking the interior and eventually produced an abundance of conidiophores from the stomata on the dark coloured needles. In the spring months these sporulating conidiophores were frequently mixed with the macroscopic ascocarps fringed with the characteristic bristle-like hairs. At almost the same time the surface of the needles became externally covered by some of the secondary saprophytes which form dark coloured superficial networks of hyphae. Of these, *Endophragmia alternata* Tubaki & Saitô, *Kriegeriella mirabilis* Höhn. and a species of unidentified dematiaceous fungus were notable. *E. alternata* has been recorded from *P. densiflora* needles by TUBAKI and SAITÔ (1969), and MATSUSHIMA (1975). Although this fungus has been also found on the fallen leaves of *Betula* and *Ilex* by ELLIS (1976), and in the evergreen oak forest by YOKOYAMA and ITO (1977), this seems usually to be the prime species of dematiaceous external colonizer associated with pine needles in this district. *K. mirabilis* has already been reported by MICHELL, MILLAR and MINTER (1978 bd) on Corsican and Scots pine needles, and also GREMMEN (1960) and LEHMANN and HUDSON (1977) as *Lophiostoma*

pinastri. These external colonizers contribute greatly to the darkening process and persist until the late blackish brown needle stage.

In more advanced stages of decay, namely the black fragmentary needles and the underlying humus soils, the foregoing groups of litter fungi were gradually eliminated and the group of so-called soil fungi started to appear. The important members of this group were invariably *Mortierella ramannianus* (Möller) Linnem., *Penicillium* spp. and *Trichoderma* spp. which were usually found using cultural methods. These members appear to be universal as many workers have described these as an important constituent the fungal flora of pine forest floors.

In conclusion, the view that pine needles habour a highly characteristic mycoflora appears to be confirmed by this study, for example, the occurrence of *L. pinastri, D. acicola* and *K. mirabilis*. In addition, there have generally been specific fungi found on each species or habitat studied, i.e. *Fusicoccum bacillare, Sympodiella acicola* and *Helicoma monospora* (KENDRICK and BURGES, 1959; PARKINSON and BALASOORIYA, 1967), *Graphium* sp. (HAYES, 1965), *Coniothyrium* species (BRANDSBERG, 1969; MILLAR, 1974) and the several species of Sphaeropsidales (WIDDEN and PARKINSON, 1973). From this point of view, *Cenangium* sp. and *E. alternata* in the present study may be regarded as the species specific to this habitat type.

2. *Basidiomycetes.*

For the present study a considerable emphasis was placed on major species from over 30 species that occurred. At first, these were divided into litter-inhabiting types and the mycorrhiza-forming types (including facultative ones), on the basis of their decomposing ability and substrate relationships.

The prominent species of litter-inhabiting basidiomycetes were *Marasmius androsaceus* (L. ex Fr.) Fr., *Collybia confluens* (Fr.) Quél and *Collybia dryophila* (Fr.) Quél (Tab. III). The fruiting of these saprophytic basidiomycetes occurred mostly in June to July and responded markedly to periods of rainfall. The fruiting of *M. androsaceus* was restricted to a very short period with high humidity in June to contrast to the occurrence of its rhizomorphs which were widespread over both the brown needles in the uppermost layer and the dark coloured needles throughout most of the year. In this connection, LEHMANN and HUDSON (1977) have reported this fungus to be an early colonizer that began to invade the needles 1 to 2 months after needle fall. The present work supports their opinion, because this agaric seemed to be a surface litter dweller which colonized the relatively new fallen needles at the early stages of decay. This fungus did not, however, appear to be as important in the decolouring process as the two species of *Collybia* were, as it adhered to the needles that were in the process of becoming dark in appearance. Undoubtedly, however, this species is also involved in the decolouring process as shown by the present cultural examination, the works of MACDONALD and MARGARET (1961) and LATTER (1977).

The most conspicuous species involved in the decolouring process here were *C. confluens* and *C. dryophila* particularly the former, associated more with frondose woods. These *Collybia* bleached the needles intensively to a yellowish colour and turned them into rag at the bottom of F_2 layer. Fur-

thermore, successful invasion by their mycelial strands occurred from the bottom to the upper layers when the moisture was adequate. There is therefore a possibility that these also begin to colonize the tensile needles such as the brown needles.

Of mycorrhizal fungi (including the putative ones) the most common 9 species are listed up in Tab. IV. On average *Suillus luteus* (Fr.) Kuntze,

TAB. IV

Relative abundance of basidiocarps of mycorrhizal fungi and their mycerial spreads in Ao layer

	Relative abundance of Basidiocarps	Mycelial spreads
Amanita pantherina (Fr.) Secr.	c	+
Cortinarius cinnamomeus (Fr.) S. F. Gray	c	++++
Suillus luteus (Fr.) S. F. Gray	a	++++
Suillus granulatus (Fr.) Kuntze	a	++++
Suillus bovinus (Fr.) Kuntze	a	++++
Russula emetica (Fr.) S. F. Gray	a	++
Russula sanguinea Fr.	c	++
Lactarius hatsudake Tanaka	a	++++
Rhizopogon rubescens (Tul.) Tul.	f	+++

Symbols: a, abundant; c, common; f, frequent; + to ++++, increasing degrees of mycelial spreads.

S. boninus (Fr.) Kuntze, *Lactarius hatsudake* Tanaka and *Russula emetica* Fr. were predominant in most years. *Suillus granulatus* (Fr.) Kuntze, *Russula sanguinea* Fr., *Cortinarius cinnamomeus* (Fr.) S. F. Gray, *Amanita pantherina* (Fr.) Secr. and *Rhizopogon rubescens* (Tul.) Tul. came next, and fluctuated from year to year. This species composition is not unusual and is similar to that of other pine woods in this country, such as the data of OGAWA (1977 a) working in Central Japan.

The occurrence of these basidiocarps was bimodal with a peak in June-July and another in September-October. Fruiting was low in August as a result of drought and high temperatures. Prior to fruiting a tremendous bulk of mycelial wefts and networks appeared in the litter layer and the surface soils. As seen in Tab. IV, these features were most obvious for three *Suillus* species, *L. hatsudake* and *C. cinnamomeus*, and to a minor degree for *R. rubescens*. On the other hand, the mycelial development of two *Russula* species and *A. pantherina* was much less than the foregoing species even around clusters of their basidiocarps. It is feasible that the mycorrhizal fungi, facultative ones at least, participate to some extent in the decaying of needles, although we have no direct evidence. Very little is known about a contribution of the mycorrhizal fungi to the decaying of litter except for a note by GADGIL and GADGIL (1971), this contrasts with the information available on occurrence and productivity (e.g. HERING, 1966; RICHARDSON, 1970; OGAWA, 1977 b). Further work is required on the role of this group.

IV. — ISOPOD POPULATIONS ASSOCIATED WITH MYCELIAL ZONES OF BASIDIOMYCETES

A. Methods.

In order to compare the population density of *P. scaber* in the mycelial zone produced by basidiomycete with that of the outer scanty mycelia, quadrats (25 × 25 cm) were placed around the basidiocarps and on three places 50 cm outside radially from there in the cases of *Lactarius* and *Suillus*. As to *Collybia* species which grow in the fairy rings in a diameter from 50 to 150 cm, the samplings were carried out in three places in the interior, just on the rings of gregarious basidiocarps and 50 cm outside, though only in one place from the interior when the ring was not large enough. Besides, to aid the understanding of the field investigation, the preliminary feeding tests of isopod were performed using these basidiocarps, and their fungal mycelia obtained from the cultural solutions.

B. Results and discussion.

As seen from Table V, the population density in the fungal zones was evidently higher than that of outside, in all cases of *Lactarius* and *Suillus*, although there were considerable differences. These increases in the density were caused by varying aggregations on the fleshly basidiocarps and on the

TAB. V

Population density (number of individual / 25 × 25 cm) of *P. scaber* around basidiocarps (mycelial zone) and 50 cm outside from basidiocarps (non-mycelial zone)

a. Mycelial zones of *Lactarius hatsudake*.

	Plots					
	A	B	C	D	E	F
Around basidiocarps	33***	25***	18***	16**	9*	7***
50 cm outside[a]	5.3	1.3	0.3	2.3	1.0	0.0

b. Mycelial zones of *Suillus luteus* or *Suillus granulatus*.

	Plots			
	A	B	C	D
Around basidiocarps	68**	33**	22**	12*
50 cm outside[a]	10.3	2.7	1.7	2.0

*, **, *** Means significantly differ from that obtained with non-mycelial zones, P = 0.05, 0.01 and 0.001 respectively, according to Chi-square tests.

[a] Average of three.

mouldy needles undernearth. A considerable number of isopods gathered clumped on the basidiocarps of *L. hatsudake* and *Suillus* species, particularly in the hollow of stem of *Lactarius* after the central part of its depressed cap had been eaten. Feeding tests in the laboratory proved that both basidiocarps, notably *L. hatsudake* were intensively eaten by the woodlouse. In addition, the same was true for mycelia of *Suillus* from the liquid culture.

In the cases of both species of *Collybia* as seen in Table VI, aggregation was found in only one of three plots just on the rings where mycelial biomass and fruit bodies concentrated. In contrast to the basidiocarps of

TAB. VI

Population density (number of individual / 25 × 25 cm) of *P. scaber* across fairy rings of litter-inhabiting basidiomycetes, consisting of interior (non-mycelial), ring (mycelial) and 50 cm outside (non-mycelial) from ring

a. Fairy ring of *Collybia confluens.*

	Plots		
	A	B	C
Interior.....	9.0	0.3	0.0
Ring.....	23.3*	3.0	4.7
Outside.....	5.0	5.7	4.0

b. Fairy ring of *Collybia dryophila.*

	Plots		
	A	B	C
Interior.....	7.0	1.5	2.0[a]
Ring.....	47.7**	6.0	4.3
Outside.....	7.0	1.0	2.3

*, ** Means significantly differ from that obtained with non mycelial zones, P = 0.05 and 0.001 respectively, according to Chi-square Tests. Numbers indicate average of three except for a.

the foregoing fungi, there was no feeding marks left on the basidiocarps of either *Collybia* in the field. The feeding test also showed that both *Collybia* refused or occasionally nibbled. Similarly, the cultural mats of two *Collybia* species are unpalatable to *P. scaber*. There may be a difference between the two groups of basidiomycetes in this respect. This fact may influence their distribution to a considerable degree. Needless to say, other factors such as an improvement in water holding capacity and the softening of needles as a result of decay may also be responsible for the increase in numbers.

In this connection, KÜHNELT (1963) working with mesofauna in the litter layer a beechwood reported that the yellow leaves infested with *Clitocybe infundibuliformis* were poor in species and the number of individuals of Collembolans, rotifers and shell bearing Amoebae. He thought that the pH and the tannin content exerted an influence on the fauna. In the cases of the litter-inhabiting hymenomycetes in the present study, other factors, mentioned above are also probably responsible for the development of isopod populations. LATTER (1977) has reported that *Rubus* litter bleached by *M.*

androsaceus gave the higher rates in the following faunal occurrence and decomposition, and also the growth of the enchytraeid worm than those of unbleached litter.

Finally, it may be pointed out here that the invasion by hymenomycetes producing prolific mycelia, notably those palatable to isopods, appears to result in a considerable increase in its population. Further study of the interactions between fungi and isopods is needed to elucidate the full course of the decaying process of pine needles.

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Summary

The soil macrofauna and mycoflora in the floor of coastal pine plantation were studied in relation to needle decay. Isopod populations, consisting of *Porcellio scaber* seemed to be the most characteristic macrofauna in terms of both density and biomass throughout a wide range of pine forests. The majority of fauna consisted of Isopoda and subordinate groups such as Araneidae, Opisthopora, Diptera and Coleoptera, distributed vertically in the A_0 layer and underlying sandy soil layer within 5 cm of the surface.

The mycoflora specific to the pine needles in this habitat was represented by *Cenangium* sp., *Endophragmia alternata* and an unidentified dematiaceous species as well as *Desmazierella acicola* and *Kiegeriella mirabilis*. Apart from the litter-inhabiting basidiomycetes such as *Collybia* and *Marasmius*, aggressive on the decaying needles, some species of the mycorrhizal fungi such as *Suillus*, *Lactarius* and *Cortinarius* produced the bulk of mycelial wefts on the outer surface of needles.

The population density of isopods was obviously high in the mycelial zones of some of the mycorrhizal fungi.

Résumé

Études écologiques des organismes du sol en relation avec la décomposition des aiguilles de pin

I. Microfaune et mycoflore d'une plantation de pins au bord de l'océan

La microfaune et microflore du sol d'une plantation de pins au bord de l'océan pacifique ont été étudiées en relation avec la décomposition des aiguilles de pin. Les populations d'Isopodes, particulièrement celles de *Porcellio scaber*, semblent être les plus caractéristiques de la microfaune, en termes de densité et biomasse, à travers un grand nombre de forêts de pins. La majorité de la faune consistait d'Isopodes et des groupes tels que Araneidae, Opisthopora, Diptères et

Coléoptères, distribués verticalement dans le niveau A_o et sous ce dernier, dans le sol sableux, à une profondeur de 5 cm.

La mycoflore spécifique aux aiguilles de pins dans ces habitats était représentée par *Cenangium* sp., *Endophragmia alternata* et une espèce non-identifiée de Dematiacée, ainsi que *Desmazierella acicola* et *Kriegeriella mirabilis*. Outre les basidiomycètes des litières tels que *Collybia* et *Marasmius* plus actifs sur les aiguilles décomposantes, des espèces de champignons mycorhiziques tels que *Suillus, Lactarius* et *Cortinarius* produisaient la plus grande partie des mycéliums fongiques sur la surface extérieure des aiguilles.

La densité des Isopodes était apparemment importante sur les zones mycéliales de quelques-uns des champignons mycorhiziques.

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